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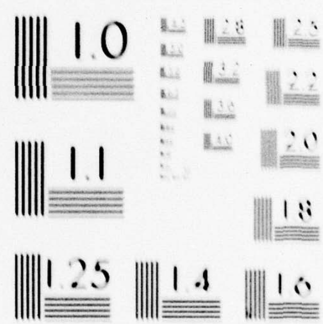

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TECHNICAL REPORT T-79-68

A COUPLED INTERIOR BALLISTICS FINITE ELEMENT COMBUSTION INSTABILITY ANALYSIS PROCEDURE — PART II

Robert M. Hackett
Technology Laboratory

26 June 1979

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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A computer code is formulated which provides the solid propellant grain designer with the capability of performing an interior ballistics analysis while, with a minimum amount of additional effort, at the same time performing a combustion instability prediction analysis at any designated point in time during the entire period of performance. The program, in effect, couples the output of an existing solid propellant grain design evaluation code, which predicts the acoustic chamber geometry during surface regression, with the input to the existing three-dimensional finite element combustion instability

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20. prediction code, FLAP3. The three-dimensional finite element mesh and boundary conditions are generated from the grain surface regression data for the progressive burn times. The entire finite element mesh and boundary condition generation by FLESH3, the companion to FLAP3, is executed with the input of seven geometry parameters, which are obtained from the ballistics code output, and the corresponding burn depth parameter. The use of the developed program is demonstrated for three different values of burn depth for the case of a typical star design.

ACKNOWLEDGMENT

The assistance of Robert Radke in developing the computer code BRNMSH and in running the numerous test cases is gratefully acknowledged.

Appreciation is expressed to the MIRADCOM Propulsion Directorate, Redstone Arsenal, the Army Research Office - Durham, and Battelle Laboratories - Durham Office for financial support of this project.

CONTENTS

ILLUSTRATIONS

1. INTRODUCTION

It has been recognized for some time that one of the major shortcomings of current combustion instability prediction technology is that it is computationally removed from conventional interior ballistic analysis. Traditionally, interior ballistics data have been extracted from an analysis and used to formulate, by hand, the problem to be run with one of the existing combustion instability prediction finite element codes. In an effort to initiate a remedy for this inefficient operation and thereby develop the basis for a more elaborate and meaningful design procedure for solid propellant rocket motors, the computer code GRNMSH (Grain Mesh) was developed.[1] This code provided an automated procedure for generating the input to a finite element mesh generator from the output of an interior ballistics code. The code GRNMSH was designed to couple the output of the 564 Interior Ballistics Computer Program,[2] developed by Aerojet-General Corporation, with the computer code FLESH3 (Fluid Mesh Generation, 3 Dimensions) which was developed as a companion finite element mesh generation program to the combustion instability prediction code FLAP3 (Fluid Analysis Program, 3 Dimensions).[3] The development of GRNMSH was considered to be of a "proof of concept" nature and stopped short of providing the complete coupling of the two codes for the entire period of performance, i.e., for the duration of propellant burning. The GRNMSH code generates the input to FLESH3 only at the instant of ignition. This report is concerned with the extension of the GRNMSH code to enable the same automatic transfer of data between the two codes at any instant in time, from propellant ignition to burnout. The extension of GRNMSH has resulted in the development of the code BRNMSH (Burn Mesh) which generates the input to FLESH3 and thus initiates the generation of a coupled fluid-solid three-dimensional finite element mesh for any specified depth of burn.

The development has concentrated on the star design, which is depicted in *Figures 1* and *2*. Similar designs can easily be handled in the same manner. A brief discussion of the previously developed codes, along with a description of BRNMSH follows.

1. R. M. Hackett, *A Coupled Interior Ballistics–Finite Element Combustion Instability Analysis Procedure*, US Army Missile Research and Development Command, Redstone Arsenal, Alabama, Technical Report T-78-72, July 1978.

2. A. E. Whetstone, T. R. Threewit, and J. S. Billheimer, *Basic Grain Design and the 564 Interior Ballistics Computer Program*, STM-143, Interior Ballistics Department, Applied Mechanics Division, Aerojet-General Corporation, Sacramento, California, June 1961.

3. R. M. Hackett and R. S. Juruf, *A Three-Dimensional Finite Element Code for Combustion Instability Prediction*, Proceedings of the 13th JANNAF Combustion Meeting, Naval Postgraduate School, Monterey, California, CPIA Publication 281, December 1976.

2. THREE-DIMENSIONAL FINITE ELEMENT MESH GENERATION

The FLAP3 code performs a linear acousto-modal analysis of the irrotational motions of an inviscid, compressible fluid coupled to the motion of a nearly incompressible, linearly viscoelastic solid, and a linear potential flow analysis of the irrotational motions of an inviscid, incompressible fluid, and then determines the effect of the flow field and of combustion on the calculated acoustic oscillations.[3] This combustion instability analysis is performed at different points in time, beginning at ignition, or time zero. The output of FLAP3 is modal frequency and an evaluation of the pressure growth/decay coefficient for each mode of vibration analyzed. A positive net value of the coefficient indicates a growth of pressure oscillations and, therefore, instability while a negative value of the coefficient is an indication of decaying oscillations, or stability.

The FLAP3 analysis utilizes the finite element method and models the acoustic cavity and propellant grain as an assemblage of three-dimensional quasi-hexahedral (each hexahedron is a combination of five tetrahedra) elements connected at the corners. In order to be realistically applicable, any three-dimensional finite element code requires a companion mesh generator; a coupled fluid-solid analysis code requires a mesh generator of more than the customary complexity. The code FLESH3 was designed to be used in conjunction with FLAP3. A detailed description of the use of FLESH3 is found in Hackett's *User's Manual for FLAP3.*[4] The code FLESH3 generates the numbered nodal points and their coordinates and identifies each node as to whether it lies in the acoustic cavity, on the cavity-grain interface, or in the grain; generates the quasi-hexahedral elements, designated by the eight numbered nodal points defining each element, and identifies each element as to whether it is a cavity element, a cavity element adjacent to the cavity-grain interface, or a solid propellant element; and generates the cavity-grain interface element surfaces (burning surfaces) and identifies each as to the direction of the surface normal. This information, along with a few additional input parameters relative to gas and propellant properties and type of acoustic mode(s) to be analyzed, is necessary and sufficient to activate a combustion instability analysis by FLAP3, given adequate computational facilities.

The input to FLESH3 is in the form of a set of global curves, defining cavity and grain boundaries; a designation of a sequence of points, as to whether they are cavity, interface or grain points; a designation of blocks of elements to be generated, by the nodal indices of the blocks; and a designation of the number and location of longitudinal cross-sections, establishing the number of layers of elements.

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4. R. M. Hackett, *User's Manual for FLAP3*, US Army Missile Research and Development Command, Redstone Arsenal, Alabama, Technical Report TK-77-4, July 1977.

The objective is that of minimizing the amount of time required to prepare the input for FLAP3 and the likelihood of error in the preparation of that data. Through the use of BRNMSH, which will be subsequently described, all of the necessary geometry and identification input data for FLAP3 can be generated with the input of seven geometry parameters, for the star design, plus one additional combustion parameter.

3. INTERIOR BALLISTICS CODE

The interior ballistics analysis code used in the formulation of BRNMSH was developed by Aerojet-General Corporation.[2] The BRNMSH geometrical input parameters are, therefore, those presented in that code, but similar parameters would be obtained from a consideration of a comparable interior ballistics code. The description of BRNMSH will be related to the Aerojet code, but the procedure followed in the development is general.

4. DEVELOPMENT OF THE BRNMSH CODE

A listing of the formulated computer code BRNMSH is found in Appendix A. The code is based upon the star design found in the report by Whetstone et al.[2] Due to the dihedral symmetry provision in FLAP3, only the smallest repeating segment need be analyzed. This segment, for the general star geometry, is shown in *Figures 1* and *2*; with the independent geometry parameters identified. The only difference between *Figure 1* and *Figure 2* is that the angle ϕ is zero in *Figure 2*. This condition necessitated a slightly different internal provision in BRNMSH. *Figures 3* and *4* define the different burning zones and the regression of the interface surface with, again, the difference in the two figures being the value of the angle ϕ. *Figure 5* shows a typical finite element mesh for burning in Zone 1. The cross-hatched portion of the segment represents the grain elements. The mesh is seen to be similar to that which would be generated for the case of zero burning. *Figure 6* shows a typical mesh for burning in Zone 2. It can be noted that the generated mesh for Zone 2 burning differs distinctly from that for Zone 1 burning. *Figure 7* shows a typical mesh for burning in Zone 3. As the burn depth increases it can be seen that the cavity geometry becomes more simply defined and this fact is thus reflected in the generated meshes of the changing cavity-grain cross-section.

A working knowledge of FLESH3[4] is necessary in order to understand the intricacies of BRNMSH, and to be able to modify and add to it, but not in order to use it. An understanding of the use of BRNMSH can be enhanced through the consideration of an example. *Table 1* lists the twelve cases of the star design upon which the formulation of BRNMSH is based. Design No. D-6c is chosen for the example. Three different burn depths are selected. They are: 0.05 in. (burning in Zone 1), 1.50 in. (burning in Zone 2), and 3.00 in. (burning in Zone

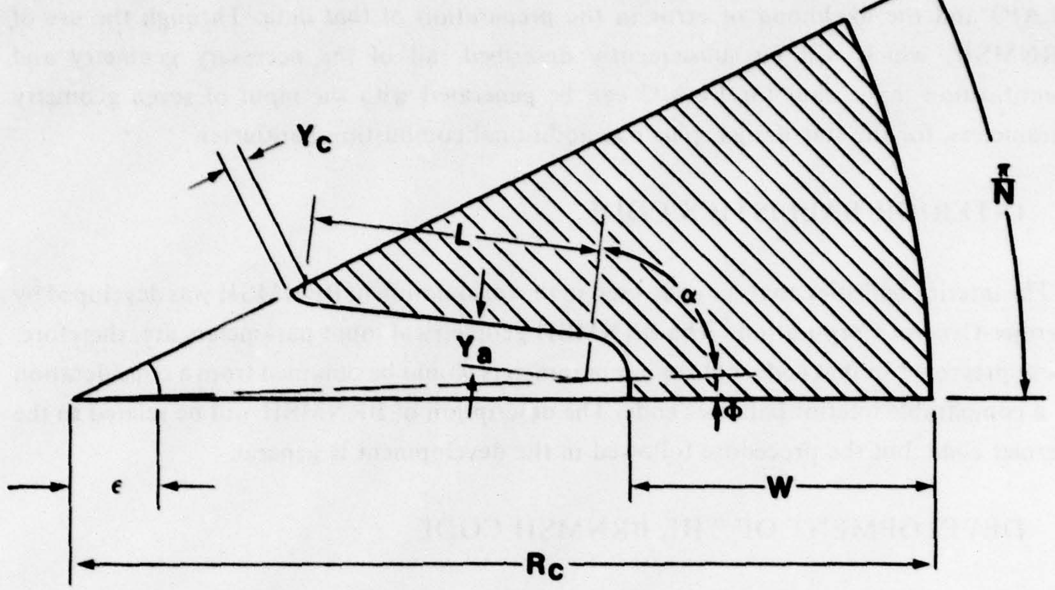

Figure 1. Cross-section of repeating segment of star design showing design parameters N, R_C, W, Y_a, α, L and Φ.

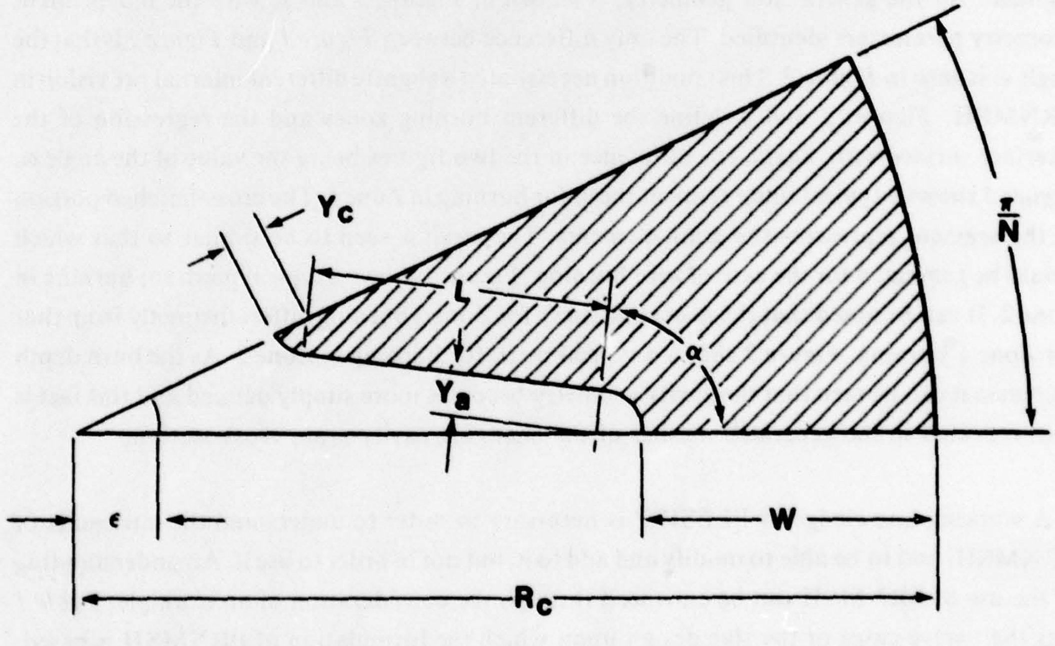

Figure 2. Cross-section of repeating segment of star design showing design parameters N, R_C, W, Y_a, α and L; $\Phi = 0$.

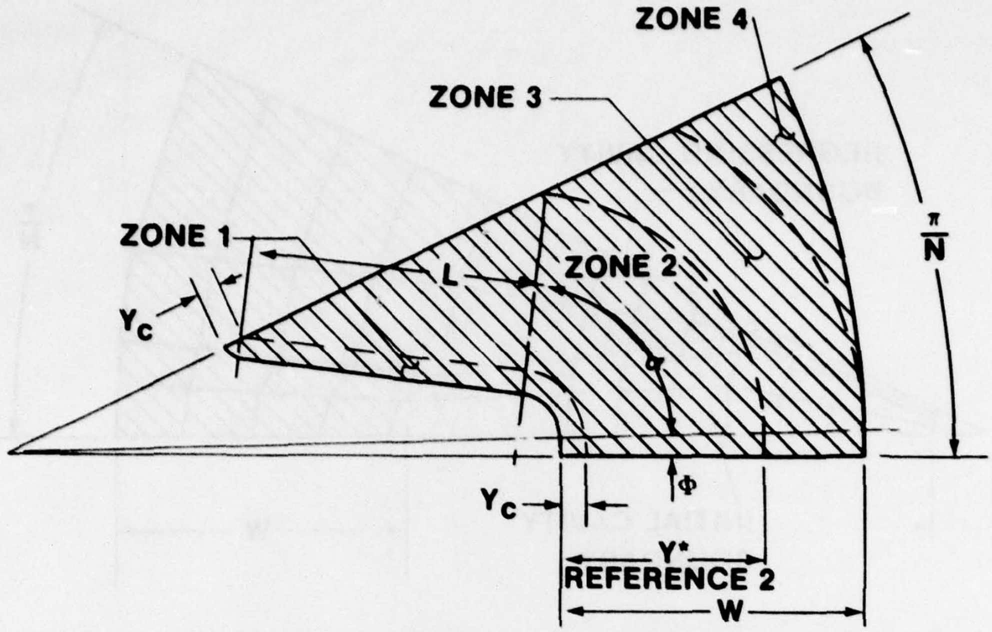

Figure 3. Cross-section of repeating segment of star design showing the four progressive burning zones.

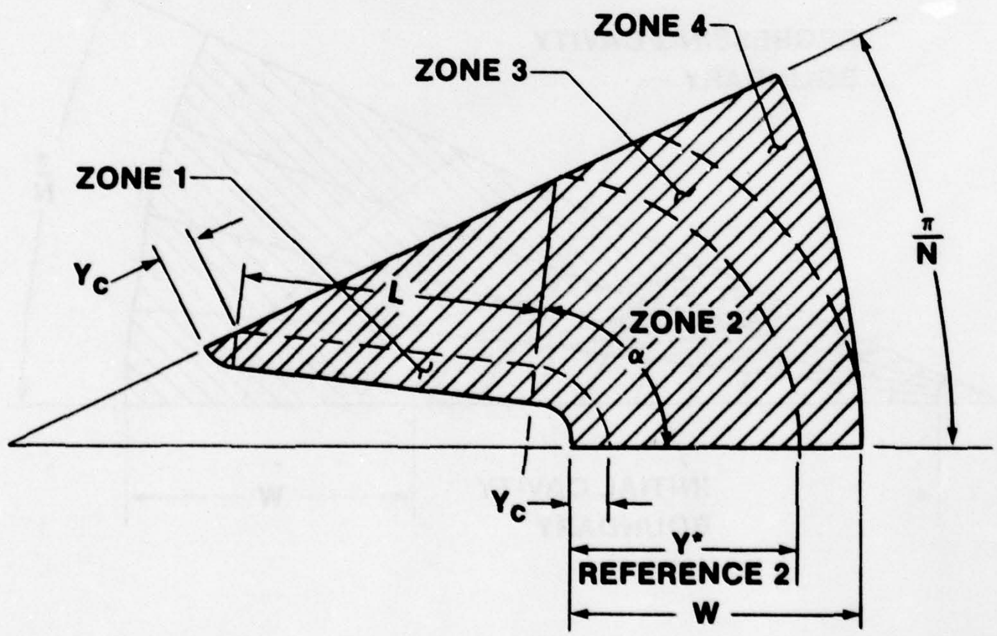

Figure 4. Cross-section of repeating segment of star design showing the four progressive burning zones; $\Phi = 0$.

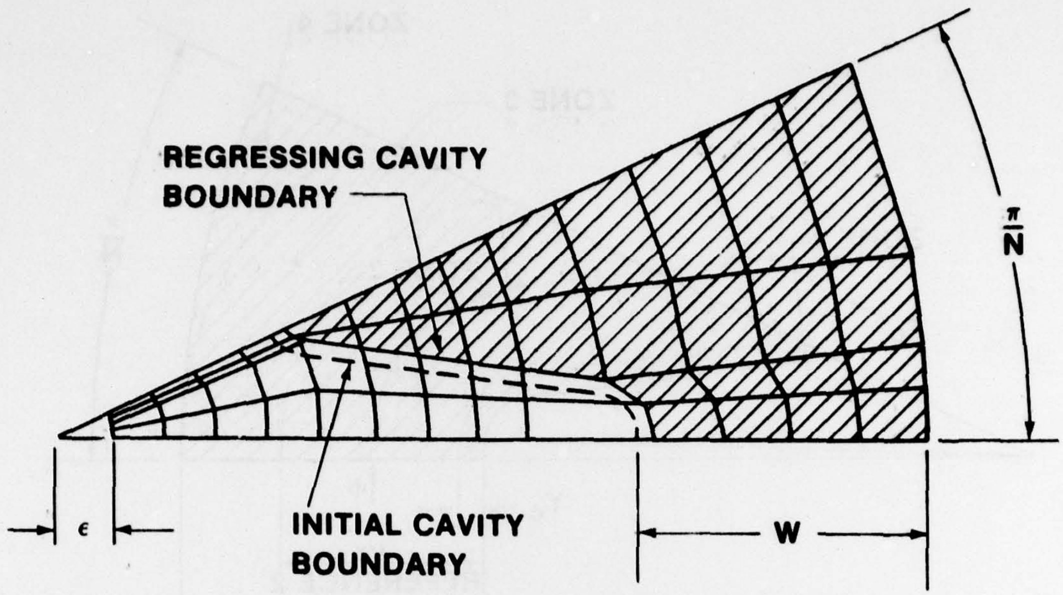

Figure 5. Finite element mesh for repeating segment of star design with Zone 1 Burning; Φ = 0.

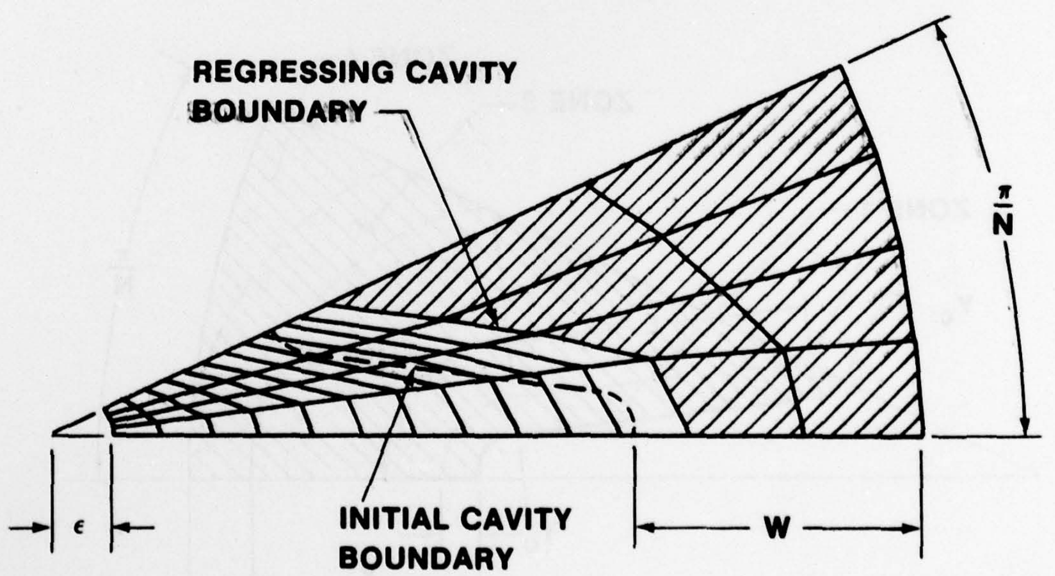

Figure 6. Finite element mesh for repeating segment of star design with Zone 2 Burning; Φ = 0.

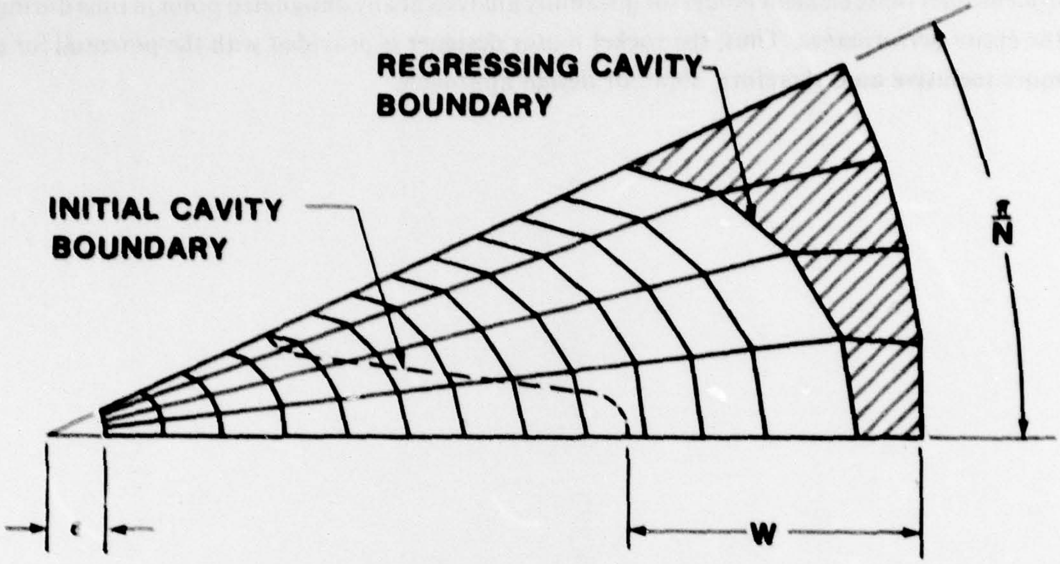

Figure 7. Finite element mesh for repeating segment of star design with Zone 3 Burning; $\Phi = 0$.

3). Each case requires the input of two data cards to BRNMSH. The first card contains the seven parameters: N, R_c, W, ϕ, Y_o, α, and L (in that order). The second card contains the burn distance, BURN. The output for the three separate cases, which is the input to FLESH3, is shown in Appendix B.

It can be noted that the length of the grain, and provision for five equidistant sections are conditions which are internally set in the program, but could, alternatively, be input as an additional set of parameters. It can also be noted that the value of ϵ, the necessary offset radius of the nodes closest to the axis origin, is internally set at 0.1 in.

There are other modifications which could be made to BRNMSH in order to increase its flexibility, for instance that of developing the capability of generating a mesh for a tapered longitudinal profile. Possible modifications such as this are obvious, but other more subtle changes could also be made which would increase the generality of the code.

5. CONCLUSIONS

A computer code has been developed which couples an interior ballistics analysis code with a combustion instability analysis code and facilitates the efficient formulation of the three-

dimensional finite element model for instability analysis at any designated point in time during the entire performance. Thus, the rocket motor designer is provided with the potential for a more inclusive and, therefore, superior design approach.

TABLE 1. STAR DESIGN PARAMETERS-SYMMETRY 7
(N = 7)

STAR (Design No.)	R_c in.	w in.	α deg	Φ deg	Y_a in.	Y_c in.	L in.
D-5a	10	3.5	80	0.0	0.2	0.075	4.3
D-5b	10	3.5	85	0.0	0.2	0.068	4.9
D-5c	10	3.5	75	0.0	0.2	0.136	3.8
D-6a	10	3.5	85	0.0	0.5	0.092	4.1
D-6b	10	3.5	80	0.0	0.5	0.118	3.6
D-6c	10	3.5	75	0.0	0.5	0.095	3.3
D-7a	10	3.5	85	2.5	0.2	0.043	4.8
D-7b	10	3.5	80	2.5	0.2	0.084	4.1
D-7c	10	3.5	75	2.5	0.2	0.047	3.7
D-8a	10	3.5	85	2.5	0.5	0.092	3.9
D-8b	10	3.5	80	2.5	0.5	0.035	3.5
D-8c	10	3.5	75	2.5	0.5	0.069	3.1

APPENDIX A

LISTING OF THE COMPUTER PROGRAM BRNMSH

```
      PROGRAM BRNMSH
     A(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH)
C     PROGRAM BRNMSH
C    A(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH)
COMMENT...
COMMENT...THIS ROUTINE DEVELOPES THE INPUT FOR FLESH3
COMMENT...STATUS-----OPERATIONAL-------18MAY79
COMMENT...
      DIMENSION X(90), Y(90), AA(90), BB(90), THI(90), THF(90)
      DIMENSION NN(90), NP(90)
      DIMENSION IEND(3)
      DATA LUI/5/, LUO/6/, LUA/7/
      DATA IEND(1)/1HE/, IEND(2)/1HN/, IEND(3)/1HD/
      DATA PI/3.14159265/, PID/180.0/, DEGRAD/1.74532925E-02/
      DATA ZERO/0.0/
      DATA IZERO/0/, NC/90/
      DATA ITITLE/10HGRAIN MESH/
 6111 FORMAT(A10)
      WRITE (LUA,6111) ITITLE
 5211 FORMAT(7E10.2)
      READ  (LUI,5211) XN, RC, W, PHID, YA, ALPHAD, XL
 5311 FORMAT(F10.2)
      READ (LUI,5311) BURN
      PHI=PHID*DEGRAD
      ALPHA=ALPHAD*DEGRAD
      THETAD=PID/XN
      THETA=THETAD*DEGRAD
      IMAX=14
      JMAX=5
      NNC=39
      IBC=3
      SCALE=1.0
      NLAY=5
      Z=ZERO
      DZ=2.0
      ZMAX=8.0
      DO 111 I=1,NC
      X(I)=ZERO
      Y(I)=ZERO
      NN(I)=IZERO
      NP(I)=IZERO
      AA(I)=ZERO
      BB(I)=ZERO
      THI(I)=ZERO
      THF(I)=ZERO
  111 CONTINUE
      EPSLON=0.1
      RCWYA=RC-W-YA
      PINPHI=THETA-PHI
      SFPHI=SIN(PINPHI)
      CFPHI=COS(PINPHI)
      DELTA=PI*0.5+THETA-PHI-ALPHA
      SFDEL=SIN(DELTA)
      CFDEL=COS(DELTA)
      SPHI=SIN(PHI)
      CPHI=COS(PHI)
      SFAP=SIN(PHI+ALPHA)
      CFAP=COS(PHI+ALPHA)
      BETA=PI*0.5-PHI-ALPHA
      SBETA=SIN(BETA)
      CBETA=COS(BETA)
      APT=ALPHA*0.5+PHI*0.5+THETA
      SAPT=SIN(APT)
      CAPT=COS(APT)
```

```
      YC=(RCWYA*SFPHI-YA*CFDEL-XL*SFDEL)/SIN(ALPHA+PHI-THETA)
      YCB=YC-BURN
      YSTAR=RCWYA*SFPHI/SIN(ALPHA+PHI-THETA)-YA
      YB=YA+BURN
      B2=BURN-YC
      B3=BURN-YSTAR
      H=(YSTAR-YC-B2)*SIN(ALPHA-THETA)/SFDEL
      H1=(YSTAR-YC-B2)*SIN(ALPHA+PHI-THETA)/SFDEL
      IF(PHI.LT.THETA.AND.BURN.LT.YC) IBC=7
 6211 FORMAT(4I5, F10.2,I5)
      WRITE (LUA,6211) IMAX, JMAX, NNC, IBC, SCALE, NLAY
  201 CONTINUE
      I=1
      NN(I)=1
      NP(I)=THETAD
      AA(I)=EPSLON
      BB(I)=EPSLON
      THF(I)=THETAD
  202 CONTINUE
      I=3
      X(I)=RC
      NN(I)=2
  203 CONTINUE
      I=4
      NN(I)=3
      NP(I)=THETAD
      AA(I)=RC
      BB(I)=RC
      THF(I)=THETAD
  204 CONTINUE
      I=6
      X(I)=RC
      Y(I)=RC*TAN(THETA)
      NN(I)=4
  205 CONTINUE
      I=7
      NN(I)=5
      NP(I)=THETAD
      AA(I)=RC-W
      BB(I)=AA(I)
      THF(I)=THETAD
  206 CONTINUE
      I=8
      CC=(RCWYA*SPHI+YB*SFAP+XL*SBETA)-(RCWYA*SPHI+YB*SFAP)
      DD=(RCWYA*CPHI+YB*CFAP)-(RCWYA*CPHI+YB*CFAP-XL*CBETA)
      SLOPE1=CC/DD
      X(I)=RCWYA*CPHI+YB*CFAP-XL*CBETA-0.1
      Y(I)=RCWYA*SPHI+YB*SFAP+XL*SBETA+0.1*SLOPE1
      I=9
      X(I)=RCWYA*CPHI+YB*CFAP+0.1
      Y(I)=RCWYA*SPHI+YB*SFAP-0.1*SLOPE1
      NN(I)=6
  207 CONTINUE
      I=10
      X(I)=RCWYA*CPHI
      Y(I)=RCWYA*SPHI
      NN(I)=7
      NP(I)=ALPHAD
      AA(I)=YB
      BB(I)=YB
      THI(I)=PHID
      THF(I)=PHID+ALPHAD
  208 CONTINUE
      I=12
      GGG=RCWYA*SPHI+YB*SFAP+XL*SBETA
      HHH=RCWYA*CPHI+YB*CFAP-XL*CBETA
```

```
      SLOPE2=GGG/HHH
      X(I)=RCWYA*CPHI+YB*CFAP-XL*CBETA+0.1
      Y(I)=RCWYA*SPHI+YB*SFAP+XL*SBETA+0.1*SLOPE2
      NN(I)=8
  209 CONTINUE
      I=13
      X(I)=RCWYA*CPHI+YB*CFAP-XL*CBETA+YCB*SBETA
      Y(I)=RCWYA*SPHI+YB*SFAP+XL*SBETA+YCB*CBETA
      NN(I)=9
      NP(I)=ALPHAD+PHID-THETAD
      AA(I)=YCB
      BB(I)=YCB
      THI(I)=PID+THETAD-1.0
      THF(I)=PID+PHID+ALPHAD+1.0
  210 CONTINUE
      I=15
      X(I)=RC
      Y(I)=RC*TAN(PHI)
      NN(I)=10
  211 CONTINUE
      I=16
      NN(I)=11
      NP(I)=THETAD
      AA(I)=((RCWYA*CFPHI+YB*SFDEL)**2+(RCWYA*SFPHI-YB*CFDEL)**2)**0.5
      BB(I)=AA(I)
      THF(I)=THETAD
  212 CONTINUE
      I=18
      X(I)=RC
      Y(I)=RC*TAN(THETA*0.5)
      NN(I)=12
  213 CONTINUE
      I=19
      NN(I)=13
      NP(I)=THETAD
      CCC=(RCWYA*CFPHI+YB*SFDEL-XL*CFDEL)**2
      DDD=(RCWYA*SFPHI-YB*CFDEL-XL*SFDEL)**2
      AA(I)=(CCC+DDD)**0.5
      BB(I)=AA(I)
      THF(I)=THETAD
  214 CONTINUE
      I=20
      EE=AA(19)*SIN(THETA*0.5)-AA(16)*SPHI
      FF=AA(16)*CPHI-AA(19)*COS(THETA*0.5)
      SLOPE3=EE/FF
      X(I)=AA(19)*COS(THETA*0.5)-0.1
      Y(I)=AA(19)*SIN(THETA*0.5)+0.1*SLOPE3
      I=21
      X(I)=AA(16)*CPHI+0.1
      Y(I)=AA(16)*SPHI-0.1*SLOPE3
      NN(I)=14
  215 CONTINUE
      I=22
      NN(I)=15
      NP(I)=THETAD
      AA(I)=EPSLON+(AA(19)-AA(1))*0.75
      BB(I)=AA(I)
      THF(I)=THETAD
  216 CONTINUE
      I=23
      GG=AA(16)*SPHI-AA(7)*SIN(PHI*0.5)
      HH=AA(7)*COS(PHI*0.5)-AA(16)*CPHI
      SLOPE4=GG/HH
      X(I)=AA(16)*CPHI-0.1
      Y(I)=AA(16)*SPHI+0.1*SLOPE4
      I=24
```

```
      X(I)=AA(7)*COS(PHI*0.5)+0.1
      Y(I)=AA(7)*SIN(PHI*0.5)-0.1*SLOPE4
      NN(I)=16
  217 CONTINUE
      I=25
      NN(I)=17
      NP(I)=THETAD
      AA(I)=AA(19)+(AA(16)-AA(19))*0.75
      BB(I)=AA(I)
      THF(I)=THETAD
  218 CONTINUE
      I=27
      X(I)=RC
      Y(I)=RC*TAN(PHI*0.5)
      NN(I)=18
  219 CONTINUE
  220 CONTINUE
      I=28
      VV=RC*(YB*SIN(ALPHA)/(RCWYA+YB*COS(ALPHA)))-RCWYA*SPHI+YB*SFAP
      WW=RC-RCWYA*CPHI+YB*CFAP
      SLOPE5=VV/WW
      X(I)=RCWYA*CPHI+YB*CFAP-0.1
      Y(I)=RCWYA*SPHI+YB*SFAP-0.1*SLOPE5
      I=29
      X(I)=RC
      Y(I)=RC*(YB*SIN(ALPHA)/(RCWYA+YB*COS(ALPHA)))
      NN(I)=20
  221 CONTINUE
  222 CONTINUE
      I=31
      X(I)=RC
      Y(I)=(RC*(YB*SIN(ALPHA)/(RCWYA+YB*COS(ALPHA))))*0.5
      NN(I)=22
  223 CONTINUE
  224 CONTINUE
      I=32
      UUU=Y(31)**2/(RC**2)
      WWW=(X(10)+((YB**2)*(1.0+UUU)-(X(10)**2)*UUU)**0.5)/(1.0+UUU)
      ZZZ=WWW*Y(31)/RC
      YYY=AA(19)*SIN(THETA*0.5)-ZZZ
      XXX=WWW-AA(19)*COS(THETA*0.5)
      SLOPE6=YYY/XXX
      X(I)=AA(19)*COS(THETA*0.5)-0.1
      Y(I)=AA(19)*SIN(THETA*0.5)+0.1*SLOPE6
      I=33
      X(I)=WWW+0.1
      Y(I)=ZZZ-0.1*SLOPE6
      NN(I)=24
  225 CONTINUE
  226 CONTINUE
      I=35
      SLOPE7=(Y(13)-YCB*SAPT)/(X(13)-YCB*CAPT)
      X(I)=X(13)-YCB*CAPT+0.1
      Y(I)=Y(13)-YCB*SAPT+0.1*SLOPE7
      NN(I)=26
  227 CONTINUE
  228 CONTINUE
      I=36
      X(I)=X(13)-YCB*CAPT-0.1
      Y(I)=Y(13)-YCB*SAPT-0.1*TAN(THETA*0.25)
      I=37
      X(I)=AA(16)
      Y(I)=Y(13)-YCB*SAPT+(AA(16)-X(13)+YCB*CAPT)*TAN(THETA*0.25)
      NN(I)=28
  229 CONTINUE
  230 CONTINUE
```

```
      I=39
      AD=X(13)-YCB*CAPT
      AE=Y(13)-YCB*SAPT
      AF=AA(15)
      AG=TAN(THETA*0.25)
      AX=AG**2.0+1.0
      AY=2.0*(AD+AE*AG)
      AZ=AD**2.0+AE**2.0-AF**2.0
      AW=(-AY+(AY**2.0-4.0*AX*AZ)**0.5)/(2.0*AX)
      BW=AW*AG
      CW=AA(7)*SIN(THETA*0.5)-(Y(13)-YCB*SAPT+BW)
      DW=AA(7)*COS(THETA*0.5)-(X(13)-YCB*CAPT+AW)
      SLOPE8=CW/DW
      X(I)=X(13)-YCB*CAPT+AW-0.1
      Y(I)=Y(13)-YCB*SAPT+BW-0.1*SLOPE8
      I=39
      X(I)=AA(7)*COS(THETA*0.5)+0.1
      Y(I)=AA(7)*SIN(THETA*0.5)+0.1*SLOPE8
      NN(I)=30
  231 CONTINUE
  232 CONTINUE
      I=40
      X(I)=RC*0.25
      Y(I)=RC*0.25*TAN(THETA*0.5)
      I=41
      X(I)=RC
      Y(I)=RC*TAN(THETA*0.5)
      NN(I)=32
  233 CONTINUE
  234 CONTINUE
      I=43
      X(I)=RC
      Y(I)=RC*TAN(THETA*0.25)
      NN(I)=34
  235 CONTINUE
  236 CONTINUE
      I=45
      X(I)=RC
      Y(I)=RC*TAN(THETA*0.50)
      NN(I)=36
  237 CONTINUE
  238 CONTINUE
      I=47
      X(I)=RC
      Y(I)=RC*TAN(THETA*0.75)
      NN(I)=38
  239 CONTINUE
  240 CONTINUE
      I=48
      AB=AA(16)*SIN(THETA*0.5)-(Y(13)-YCB*SAPT)
      AC=AA(16)*COS(THETA*0.5)-(X(13)-YCB*CAPT)
      SLOPE9=AB/AC
      X(I)=X(13)-YCB*CAPT-0.1
      Y(I)=Y(13)-YCB*SAPT-0.1*SLOPE9
      I=49
      X(I)=AA(16)*COS(THETA*0.5)+0.1
      Y(I)=AA(15)*SIN(THETA*0.5)+0.1*SLOPE9
      NN(I)=40
  241 CONTINUE
  242 CONTINUE
      I=50
      X(I)=RCWYA+(YA+YC+B2)
      I=51
      X(I)=RCWYA+(YA+YC+B2)*COS(ALPHA/3.0)
      Y(I)=(YA+YC+B2)*SIN(ALPHA/3.0)
      I=52
```

```
      X(I)=RCWYA+(YA+YC+B2)*COS(ALPHA*2.0/3.0)
      Y(I)=(YA+YC+B2)*SIN(ALPHA*2.0/3.0)
      I=53
      X(I)=RCWYA+(YA+YC+B2)*COS(ALPHA)
      Y(I)=(YA+YC+B2)*SIN(ALPHA)
      I=54
      X(I)=X(53)-H*COS(PI*0.5-ALPHA)/2.0
      Y(I)=Y(53)+H*SIN(PI*0.5-ALPHA)/2.0
      I=55
      X(I)=X(53)-H*COS(PI*0.5-ALPHA)
      Y(I)=Y(53)+H*SIN(PI*0.5-ALPHA)
      NN(I)=42
  243 CONTINUE
      I=56
      X(I)=RCWYA
      NN(I)=43
      NP(I)=ALPHAD
      AA(I)=YA+YC+B3
      BB(I)=AA(I)
      THE(I)=ALPHAD
  244 CONTINUE
      I=57
      X(I)=X(50)/1.125
      I=58
      X(I)=X(51)/1.125
      Y(I)=Y(51)/1.125
      I=59
      X(I)=X(52)/1.125
      Y(I)=Y(52)/1.125
      I=60
      X(I)=X(53)/1.125
      Y(I)=Y(53)/1.125
      I=61
      X(I)=X(54)/1.125
      Y(I)=Y(54)/1.125
      I=62
      X(I)=X(55)/1.125
      Y(I)=Y(55)/1.125
      NN(I)=44
  245 CONTINUE
      I=63
      X(I)=SCWYA
      NN(I)=45
      NP(I)=ALPHAD
      AA(I)=AA(56)/1.125
      BB(I)=AA(I)
      THE(I)=ALPHAD
  246 CONTINUE
      I=64
      X(I)=RCWYA+(YA+YC+B2)
      I=65
      X(I)=(RC-W+YC+B2)*CPHI
      Y(I)=(RC-W+YC+B2)*SPHI
      I=66
      X(I)=RCWYA*CPHI+(YA+YC+B2)*COS(PHI+ALPHA/3.0)
      Y(I)=RCWYA*SPHI+(YA+YC+B2)*SIN(PHI+ALPHA/3.0)
      I=67
      X(I)=RCWYA*CPHI+(YA+YC+B2)*COS(PHI+ALPHA*2.0/3.0)
      Y(I)=RCWYA*SPHI+(YA+YC+B2)*SIN(PHI+ALPHA*2.0/3.0)
      I=68
      X(I)=RCWYA*CPHI+(YA+YC+B2)*CFAP
      Y(I)=RCWYA*SPHI+(YA+YC+B2)*SFAP
      I=69
      X(I)=X(68)-H1*CBETA/2.0
      Y(I)=Y(68)+H1*SBETA/2.0
      I=70
```

```
      X(I)=X(68)-H1*CBETA
      Y(I)=Y(68)+H1*SBETA
      NN(I)=46
  247 CONTINUE
      I=71
      NN(I)=47
      NP(I)=PHID
      AA(I)=RC-W+YC+B3
      BB(I)=AA(I)
      THF(I)=PHID
  248 CONTINUE
      I=72
      X(I)=X(64)/1.125
      I=73
      X(I)=X(65)/1.125
      Y(I)=Y(65)/1.125
      I=74
      X(I)=X(66)/1.125
      Y(I)=Y(66)/1.125
      I=75
      X(I)=X(67)/1.125
      Y(I)=Y(67)/1.125
      I=76
      X(I)=X(68)/1.125
      Y(I)=Y(68)/1.125
      I=77
      X(I)=X(69)/1.125
      Y(I)=Y(69)/1.125
      I=78
      X(I)=X(70)/1.125
      Y(I)=Y(70)/1.125
      NN(I)=48
  249 CONTINUE
      I=79
      X(I)=RCWYA*CPHI
      Y(I)=RCWYA*SPHI
      NN(I)=49
      NP(I)=ALPHAD
      AA(I)=YA+YC+B3
      BB(I)=AA(I)
      THF(I)=ALPHAD
  250 CONTINUE
  251 CONTINUE
      I=80
      NN(I)=51
      NP(I)=PHID
      AA(I)=AA(71)/1.125
      BB(I)=AA(I)
      THF(I)=PHID
  252 CONTINUE
  253 CONTINUE
      I=81
      X(I)=RCWYA*CPHI
      Y(I)=RCWYA*SPHI
      NN(I)=53
      NP(I)=ALPHAD
      AA(I)=AA(79)/1.125
      BB(I)=AA(I)
      THF(I)=ALPHAD
  299 CONTINUE
      DO 331 I=1,81
      WRITE (LUA,6331) X(I),Y(I),NN(I),NP(I),AA(I),BB(I),THI(I),THF(I)
  331 CONTINUE
 6331 FORMAT(2F10.4,2I5,4F10.4)
      IM1=-1
      II=ZERO
```

```
      IJ=1
      IK=2
      IL=3
      IM=4
      IN=5
      IP=6
      IQ=7
      IR=8
      IS=9
      JI=10
      JJ=11
      JK=12
      JL=13
      JM=14
      JN=15
      JP=16
      JQ=17
      JR=18
      JS=19
      KI=20
      KJ=21
      KK=22
      KL=23
      KM=24
      KN=25
      KP=26
      KQ=27
      KR=28
      KS=29
      LI=30
      LJ=31
      LK=32
      LL=33
      LM=34
      LN=35
      LP=36
      LQ=37
      LR=38
      LS=39
      MI=40
      MJ=41
      MK=42
      ML=43
      MM=44
      MN=45
      MP=46
      MQ=47
      MR=48
      MS=49
      NI=50
      NJ=51
      NK=52
      NL=53
      IZONE=0
      IF(BURN.LT.YC) IZONE=1
      IF(BURN.GE.YC .AND. BURN.LT.YSTAR) IZONE=2
      IF(BURN.GE.YSTAR .AND. BURN.LE.W) IZONE=3
      IF(IZONE.NE.0) GO TO 440
  439 CONTINUE
      WRITE (LUO,6439) BURN,YC,YSTAR,W
 6439 FORMAT (11H ZONE ERROR ,/,4(1X,F10.4))
      GO TO 999
  440 CONTINUE
      IF (PHI.LT.THETA) GO TO 442
 6373 FORMAT (5I5)
      WRITE (LUA,6373) IJ,IJ,IJ,IS,IN
```

```
      WRITE (LUA,6373) IK,JI,IJ,JI,IN
      WRITE (LUA,6373) IL,JJ,IJ,JM,IN
  441 CONTINUE
 6443 FORMAT (14I5)
      WRITE (LUA,6443) IJ,IJ,IJ,IS,IK,IK,JJ,LM,IJ,IJ,II,II,II,II
      WRITE (LUA,6443) IK,IJ,IK,IS,IL,LM,JJ,LP,IJ,IJ,II,II,II,II
      WRITE (LUA,6443) IL,IJ,IL,IS,IM,LP,JJ,LR,IJ,IJ,II,II,II,II
      WRITE (LUA,6443) IM,IJ,IM,IS,IN,LR,JJ,IM,IJ,IJ,II,II,II,II
      WRITE (LUA,6443) IN,IS,IJ,JI,IK,IK,IN,LM,JJ,IK,II,II,II,II
      WRITE (LUA,6443) IP,IS,IK,JI,IL,LM,IN,LP,JJ,IK,II,II,II,II
      WRITE (LUA,6443) IQ,IS,IL,JI,IM,LP,IN,LR,JJ,IK,II,II,II,II
      WRITE (LUA,6443) IR,IS,IM,JI,IN,LR,IN,IM,JJ,IK,II,II,II,II
      WRITE (LUA,6443) IS,JI,IJ,JM,IK,IK,IL,LM,IN,IL,II,II,II,II
      WRITE (LUA,6443) JI,JI,IK,JM,IL,LM,IL,LP,IN,IL,II,II,II,II
      WRITE (LUA,6443) JJ,JI,IL,JM,IM,LP,IL,LR,IN,IL,II,II,II,II
      WRITE (LUA,6443) JK,JI,IM,JM,IN,LR,IL,IM,IN,IL,II,II,II,II
      WRITE (LUA,6443) IM1,II,II,II,II,II,II,II,II,II,II,II,II,II
      GO TO 450
  442 CONTINUE
      IF(IZONE.NE.1) GO TO 444
 6332 FORMAT(5I5)
      WRITE (LUA,6332) IJ,IJ,IJ,IM,IM
      WRITE (LUA,6332) IJ,IN,IJ,IS,IK
      WRITE (LUA,6332) IK,IN,IL,IN,IN
      WRITE (LUA,6332) IK,IP,IL,IS,IL
      WRITE (LUA,6332) IK,JI,IJ,JI,IL
      WRITE (LUA,6332) IL,IP,IM,JM,IN
      WRITE (LUA,6332) IL,JJ,IJ,JM,IL
  443 CONTINUE
      IF(PHI.EQ.0.0) GO TO 445
 6441 FORMAT(14I5)
      WRITE (LUA,6441) IJ,IJ,IJ,IN,IK,IK,JL,JK,IJ,IJ,II,II,II,II
      WRITE (LUA,6441) IK,IJ,IK,IN,IL,JK,JL,IR,IJ,IJ,II,II,II,II
      WRITE (LUA,6441) IL,IJ,IL,IM,IM,IR,JN,KP,IJ,IJ,II,II,II,II
      WRITE (LUA,6441) IM,IJ,IM,IM,IN,KP,JN,IM,IJ,IJ,II,II,II,II
      WRITE (LUA,6441) IN,IN,IJ,IS,IK,IK,JJ,JM,JL,IJ,II,II,II,II
      WRITE (LUA,6441) IP,IM,IL,IN,IM,IR,IS,KP,JN,IK,II,II,II,II
      WRITE (LUA,6441) IQ,IM,IM,IN,IN,KP,IS,IM,JN,IK,II,II,II,II
      WRITE (LUA,6441) IR,IN,IK,IS,IL,JM,JJ,IP,JL,IK,II,II,II,II
      WRITE (LUA,6441) IS,IS,IJ,JI,IK,IK,IN,JP,JJ,IK,II,II,II,II
      WRITE (LUA,6441) JI,IS,IK,JI,IL,JP,IN,IG,JJ,IK,II,II,II,II
      WRITE (LUA,6441) JJ,IN,IL,IS,IM,IP,JJ,KR,IS,IL,II,II,II,II
      WRITE (LUA,6441) JK,IN,IM,IS,IN,KR,JJ,IM,IS,IL,II,II,II,II
      WRITE (LUA,6441) JL,IS,IL,JI,IM,IQ,IN,LI,JJ,IL,II,II,II,II
      WRITE (LUA,6441) JM,IS,IM,JI,IN,LI,IN,IM,JJ,IL,II,II,II,II
      WRITE (LUA,6441) JN,JI,IJ,JM,IK,IK,IL,JR,IN,IL,II,II,II,II
      WRITE (LUA,6441) JP,JI,IK,JM,IL,JR,IL,JI,IN,IL,II,II,II,II
      WRITE (LUA,6441) JQ,JI,IL,JM,IM,JI,IL,LK,IN,IL,II,II,II,II
      WRITE (LUA,6441) JR,JI,IM,JM,IN,LK,IL,IM,IN,IL,II,II,II,II
      WRITE (LUA,6441) IM1,II,II,II,II,II,II,II,II,II,II,II,II,II
      GO TO 450
  445 CONTINUE
 6442 FORMAT (14I5)
      WRITE (LUA,6442) IJ,IJ,IJ,IN,IK,IK,JL,JK,IJ,IJ,II,II,II,II
      WRITE (LUA,6442) IK,IJ,IK,IN,IL,JK,JL,IR,IJ,IJ,II,II,II,II
      WRITE (LUA,6442) IL,IJ,IL,IM,IM,IR,JN,KP,IJ,IJ,II,II,II,II
      WRITE (LUA,6442) IM,IJ,IM,IM,IN,KP,JN,IM,IJ,IJ,II,II,II,II
      WRITE (LUA,6442) IN,IN,IJ,IS,IK,IK,JQ,KM,JL,IJ,II,II,II,II
      WRITE (LUA,6442) IP,IM,IL,IN,IM,IR,IS,KP,JN,IK,II,II,II,II
      WRITE (LUA,6442) IG,IM,IM,IN,IN,KP,IS,IM,JN,IK,II,II,II,II
      WRITE (LUA,6442) IR,IN,IK,IS,IL,KM,JQ,IP,JL,IK,II,II,II,II
      WRITE (LUA,6442) IS,IS,IJ,JI,IK,IK,IQ,KM,JQ,IK,II,II,II,II
      WRITE (LUA,6442) JI,IS,IK,JI,IL,KM,IQ,IP,JQ,IK,II,II,II,II
      WRITE (LUA,6442) JJ,IN,IL,IS,IM,IP,JQ,MI,IS,IL,II,II,II,II
      WRITE (LUA,6442) JK,IN,IM,IS,IN,MI,JG,IM,IS,IL,II,II,II,II
      WRITE (LUA,6442) JL,IS,IL,JI,IM,IP,JJ,MI,JG,IL,II,II,II,II
```

```
      WRITE (LUA,6442) JM,IS,IM,JI,IN,MI,JJ,IM,JQ,IL,II,II,II,II
      WRITE (LUA,6442) JN,JI,IJ,JM,IK,IK,IL,KK,IQ,IL,II,II,II,II
      WRITE (LUA,6442) JP,JI,IK,JM,IL,KK,IL,KI,IQ,IL,II,II,II,II
      WRITE (LUA,6442) JQ,JI,IL,JM,IM,KI,IL,LM,JJ,IL,II,II,II,II
      WRITE (LUA,6442) JR,JI,IM,JM,IN,LK,IL,IM,JJ,IL,II,II,II,II
      WRITE (LUA,6442) IM1,II,II,II,II,II,II,II,II,II,II,II,II,II
      GO TO 450
  444 CONTINUE
      IF(IZONE.NE.2) GO TO 446
 6334 FORMAT (5I5)
      WRITE (LUA,6334) IJ,IJ,IJ,JJ,IN
      WRITE (LUA,6334) IK,JK,IJ,JK,IN
      WRITE (LUA,6334) IL,JL,IJ,JM,IN
  447 CONTINUE
      IF(PHI.EQ.0.0) GO TO 449
 6447 FORMAT (14I5)
      WRITE (LUA,6447) IJ,IJ,IJ,JJ,IN,IK,MR,IM,IJ,IJ,II,II,II,IJ
      WRITE (LUA,6447) IK,JJ,IJ,JK,IN,IK,MP,IM,MR,IK,II,II,II,II
      WRITE (LUA,6447) IL,JK,IJ,JM,IN,IK,IL,IK,MP,IL,II,II,II,IJ
      WRITE (LUA,6447) IM1,II,II,II,II,II,II,II,II,II,II,II,II,II
      GO TO 450
  449 CONTINUE
 6445 FORMAT (14I5)
      WRITE (LUA,6445) IJ,IJ,IJ,JJ,IN,IK,MM,IM,IJ,IJ,II,II,II,IJ
      WRITE (LUA,6445) IK,JJ,IJ,JK,IN,IK,MK,IM,MM,IK,II,II,II,II
      WRITE (LUA,6445) IL,JK,IJ,JM,IN,IK,IL,IM,MK,IL,II,II,II,IJ
      WRITE (LUA,6445) IM1,II,II,II,II,II,II,II,II,II,II,II,II,II
      GO TO 450
  446 CONTINUE
      IF(IZONE.NE.3) GO TO 499
 6336 FORMAT (5I5)
      WRITE (LUA,6336) IJ,IJ,IJ,JK,IN
      WRITE (LUA,6336) IK,JL,IJ,JL,IN
      WRITE (LUA,6336) IL,JM,IJ,JM,IN
  451 CONTINUE
      IF(PHI.EQ.0.0) GO TO 453
 6448 FORMAT (14I5)
      WRITE (LUA,6448) IJ,IJ,IJ,JK,IK,IK,NJ,JI,IJ,IJ,II,II,II,IJ
      WRITE (LUA,6448) IK,IJ,IK,JK,IN,JI,NL,IM,IJ,IJ,II,II,II,IJ
      WRITE (LUA,6448) IL,JK,IJ,JL,IK,IK,MQ,JI,NJ,IK,II,II,II,II
      WRITE (LUA,6448) IM,JK,IK,JL,IN,JI,MS,IM,NL,IK,II,II,II,II
      WRITE (LUA,6448) IN,JL,IJ,JM,IK,IK,IL,JI,MQ,IL,II,II,II,II
      WRITE (LUA,6448) IP,JL,IK,JM,IN,JI,IL,IM,MS,IL,II,II,II,II
      WRITE (LUA,6448) IM1,II,II,II,II,II,II,II,II,II,II,II,II,II
      GO TO 450
  453 CONTINUE
 6446 FORMAT (14I5)
      WRITE (LUA,6446) IJ,IJ,IJ,JK,IN,IK,MN,IM,IJ,IJ,II,II,II,IJ
      WRITE (LUA,6446) IK,JK,IJ,JL,IN,IK,ML,IM,MN,IK,II,II,II,II
      WRITE (LUA,6446) IL,JL,IJ,JM,IN,IK,IL,IM,ML,IL,II,II,II,II
      WRITE (LUA,6446) IM1,II,II,II,II,II,II,II,II,II,II,II,II,II
  450 CONTINUE
 6444 FORMAT(F10.4)
      WRITE (LUA,6444) Z
      Z=Z+DZ
      IF(Z.GT.ZMAX) GO TO 999
  455 CONTINUE
      IF(IZONE.EQ.1) GO TO 443
  456 CONTINUE
      IF(IZONE.EQ.2) GO TO 447
  457 CONTINUE
      IF(IZONE.EQ.3) GO TO 451
  454 CONTINUE
      IF(PHI.LT.THETA) GO TO 441
 6333 FORMAT(3A1)
      WRITE (LUA,6333) (IEND(I),I=1,3)
```

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999 CONTINUE
    STOP
    END
```

APPENDIX B

EXAMPLE THREE-DIMENSIONAL FINITE ELEMENT MESH GENERATION INPUT FOR STAR DESIGN

Zone I Burning

GRAIN MESH

14 5	39 7		1.00	5			
0.0000	0.0000	1	25	.1000	.1000	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	2	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	3	25	10.0000	10.0000	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	4.8157	4	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	5	25	6.5000	6.5000	0.0000	25.7143
2.8548	1.4122	0	0	0.0000	0.0000	0.0000	0.0000
6.2424	.5045	6	0	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	7	75	.5500	.5500	0.0000	75.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
3.0548	1.4322	8	0	0.0000	0.0000	0.0000	0.0000
2.9664	1.4285	9	49	.0447	.0447	204.7143	256.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	10	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	11	25	6.1653	6.1653	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	12	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	13	25	3.2634	3.2634	0.0000	25.7143
3.0816	.7505	0	0	0.0000	0.0000	0.0000	0.0000
6.2653	-.0243	14	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	15	25	2.4726	2.4726	0.0000	25.7143
6.0653	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
6.6000	0.0000	16	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	17	25	5.4398	5.4398	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	18	0	0.0000	0.0000	0.0000	0.0000
6.0424	.4976	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	.8649	20	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	.4325	22	0	0.0000	0.0000	0.0000	0.0000
3.0816	.7397	0	0	0.0000	0.0000	0.0000	0.0000
6.5734	.2664	24	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
3.0462	1.4358	26	0	0.0000	0.0000	0.0000	0.0000
2.8462	1.3774	0	0	0.0000	0.0000	0.0000	0.0000
6.1653	1.7513	28	0	0.0000	0.0000	0.0000	0.0000
5.8194	1.7900	0	0	0.0000	0.0000	0.0000	0.0000
6.4370	1.3800	30	0	0.0000	0.0000	0.0000	0.0000
2.5000	.5706	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	32	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	1.1267	34	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	36	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	3.4992	38	0	0.0000	0.0000	0.0000	0.0000
2.8462	1.3892	0	0	0.0000	0.0000	0.0000	0.0000
6.1107	1.3714	40	0	0.0000	0.0000	0.0000	0.0000
6.5500	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
6.4985	.2324	0	0	0.0000	0.0000	0.0000	0.0000
6.3535	.4213	0	0	0.0000	0.0000	0.0000	0.0000
6.1424	.5313	0	0	0.0000	0.0000	0.0000	0.0000
4.5235	.9650	0	0	0.0000	0.0000	0.0000	0.0000
2.9046	1.3988	42	0	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	43	75	-2.2899	-2.2899	0.0000	75.0000
5.8222	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
5.7764	.2066	0	0	0.0000	0.0000	0.0000	0.0000
5.6476	.3745	0	0	0.0000	0.0000	0.0000	0.0000
5.4599	.4722	0	0	0.0000	0.0000	0.0000	0.0000
4.0209	.8578	0	0	0.0000	0.0000	0.0000	0.0000
2.5819	1.2434	44	0	0.0000	0.0000	0.0000	0.0000

```
6.0000     0.0000    45    75    -2.0354    -2.0354    0.0000    75.0000
6.5500     0.0000     0     0     0.0000     0.0000    0.0000     0.0000
6.5500     0.0000     0     0     0.0000     0.0000    0.0000     0.0000
6.4985      .2324     0     0     0.0000     0.0000    0.0000     0.0000
6.3535      .4213     0     0     0.0000     0.0000    0.0000     0.0000
6.1424      .5313     0     0     0.0000     0.0000    0.0000     0.0000
4.5235      .9650     0     0     0.0000     0.0000    0.0000     0.0000
2.9046     1.3988    46     0     0.0000     0.0000    0.0000     0.0000
0.0000     0.0000    47     0     3.7101     3.7101    0.0000     0.0000
5.8222     0.0000     0     0     0.0000     0.0000    0.0000     0.0000
5.8222     0.0000     0     0     0.0000     0.0000    0.0000     0.0000
5.7764      .2066     0     0     0.0000     0.0000    0.0000     0.0000
5.6476      .3745     0     0     0.0000     0.0000    0.0000     0.0000
5.4599      .4722     0     0     0.0000     0.0000    0.0000     0.0000
4.0209      .8578     0     0     0.0000     0.0000    0.0000     0.0000
2.5819     1.2434    48     0     0.0000     0.0000    0.0000     0.0000
6.0000     0.0000    49    75    -2.2899    -2.2899    0.0000    75.0000
0.0000     0.0000    51     0     3.2979     3.2979    0.0000     0.0000
6.0000     0.0000    53    75    -2.0354    -2.0354    0.0000    75.0000
  1    1     1    4     5
  1    5     1    9     2
  2    5     3    5     5
  2    6     3    9     3
  2   10     1   10     3
  3    6     4   14     5
  2   11     1   14     3
  1    1     1    5     2    2   13   12    1    1    0    0    0    0
  2    1     2    5     3   12   13    8    1    1    0    0    0    0
  3    1     3    4     4    8   15   26    1    1    0    0    0    0
  4    1     4    4     5   26   15    4    1    1    0    0    0    0
  5    5     1    9     2    2   17   24   13    1    0    0    0    0
  6    4     3    5     4    8    9   26   15    2    0    0    0    0
  7    4     4    5     5   26    9    4   15    2    0    0    0    0
  8    5     2    9     3   24   17    6   13    2    0    0    0    0
  9    9     1   10     2    2    7   24   17    2    0    0    0    0
 10    9     2   10     3   24    7    6   17    2    0    0    0    0
 11    5     3    9     4    6   17   40    9    3    0    0    0    0
 12    5     4    9     5   40   17    4    9    3    0    0    0    0
 13    9     3   10     4    6   11   40   17    3    0    0    0    0
 14    9     4   10     5   40   11    4   17    3    0    0    0    0
 15   10     1   14     2    2    3   22    7    3    0    0    0    0
 16   10     2   14     3   22    3   20    7    3    0    0    0    0
 17   10     3   14     4   20    3   32   11    3    0    0    0    0
 18   10     4   14     5   32    3    4   11    3    0    0    0    0
 -1    0     0    0     0    0    0    0    0    0    0    0    0    0
  0.0000
  1    1     1    5     2    2   13   12    1    1    0    0    0    0
  2    1     2    5     3   12   13    8    1    1    0    0    0    0
  3    1     3    4     4    8   15   26    1    1    0    0    0    0
  4    1     4    4     5   26   15    4    1    1    0    0    0    0
  5    5     1    9     2    2   17   24   13    1    0    0    0    0
  6    4     3    5     4    8    9   26   15    2    0    0    0    0
  7    4     4    5     5   26    9    4   15    2    0    0    0    0
  8    5     2    9     3   24   17    6   13    2    0    0    0    0
  9    9     1   10     2    2    7   24   17    2    0    0    0    0
 10    9     2   10     3   24    7    6   17    2    0    0    0    0
 11    5     3    9     4    6   17   40    9    3    0    0    0    0
 12    5     4    9     5   40   17    4    9    3    0    0    0    0
 13    9     3   10     4    6   11   40   17    3    0    0    0    0
 14    9     4   10     5   40   11    4   17    3    0    0    0    0
 15   10     1   14     2    2    3   22    7    3    0    0    0    0
 16   10     2   14     3   22    3   20    7    3    0    0    0    0
 17   10     3   14     4   20    3   32   11    3    0    0    0    0
 18   10     4   14     5   32    3    4   11    3    0    0    0    0
 -1    0     0    0     0    0    0    0    0    0    0    0    0    0
  2.0000
```

1	1	1	5	2	2	13	12	1	1	0	0	0	0
2	1	2	5	3	12	13	8	1	1	0	0	0	0
3	1	3	4	4	8	15	26	1	1	0	0	0	0
4	1	4	4	5	26	15	4	1	1	0	0	0	0
5	5	1	9	2	2	17	24	13	1	0	0	0	0
6	4	3	5	4	8	9	26	15	2	0	0	0	0
7	4	4	5	5	26	9	4	15	2	0	0	0	0
8	5	2	9	3	24	17	6	13	2	0	0	0	0
9	9	1	10	2	2	7	24	17	2	0	0	0	0
10	9	2	10	3	24	7	6	17	2	0	0	0	0
11	5	3	9	4	6	17	40	9	3	0	0	0	0
12	5	4	9	5	40	17	4	9	3	0	0	0	0
13	9	3	10	4	6	11	40	17	3	0	0	0	0
14	9	4	10	5	40	11	4	17	3	0	0	0	0
15	10	1	14	2	2	3	22	7	3	0	0	0	0
16	10	2	14	3	22	3	20	7	3	0	0	0	0
17	10	3	14	4	20	3	32	11	3	0	0	0	0
18	10	4	14	5	32	3	4	11	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
4.0000													
1	1	1	5	2	2	13	12	1	1	0	0	0	0
2	1	2	5	3	12	13	8	1	1	0	0	0	0
3	1	3	4	4	8	15	26	1	1	0	0	0	0
4	1	4	4	5	26	15	4	1	1	0	0	0	0
5	5	1	9	2	2	17	24	13	1	0	0	0	0
6	4	3	5	4	8	9	26	15	2	0	0	0	0
7	4	4	5	5	26	9	4	15	2	0	0	0	0
8	5	2	9	3	24	17	6	13	2	0	0	0	0
9	9	1	10	2	2	7	24	17	2	0	0	0	0
10	9	2	10	3	24	7	6	17	2	0	0	0	0
11	5	3	9	4	6	17	40	9	3	0	0	0	0
12	5	4	9	5	40	17	4	9	3	0	0	0	0
13	9	3	10	4	6	11	40	17	3	0	0	0	0
14	9	4	10	5	40	11	4	17	3	0	0	0	0
15	10	1	14	2	2	3	22	7	3	0	0	0	0
16	10	2	14	3	22	3	20	7	3	0	0	0	0
17	10	3	14	4	20	3	32	11	3	0	0	0	0
18	10	4	14	5	32	3	4	11	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
6.0000													
1	1	1	5	2	2	13	12	1	1	0	0	0	0
2	1	2	5	3	12	13	8	1	1	0	0	0	0
3	1	3	4	4	8	15	26	1	1	0	0	0	0
4	1	4	4	5	26	15	4	1	1	0	0	0	0
5	5	1	9	2	2	17	24	13	1	0	0	0	0
6	4	3	5	4	8	9	26	15	2	0	0	0	0
7	4	4	5	5	26	9	4	15	2	0	0	0	0
8	5	2	9	3	24	17	6	13	2	0	0	0	0
9	9	1	10	2	2	7	24	17	2	0	0	0	0
10	9	2	10	3	24	7	6	17	2	0	0	0	0
11	5	3	9	4	6	17	40	9	3	0	0	0	0
12	5	4	9	5	40	17	4	9	3	0	0	0	0
13	9	3	10	4	6	11	40	17	3	0	0	0	0
14	9	4	10	5	40	11	4	17	3	0	0	0	0
15	10	1	14	2	2	3	22	7	3	0	0	0	0
16	10	2	14	3	22	3	20	7	3	0	0	0	0
17	10	3	14	4	20	3	32	11	3	0	0	0	0
18	10	4	14	5	32	3	4	11	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
8.0000													

Zone 2 Burning

GRAIN MESH

14 5 39 3 1.00 5

0.0000	0.0000	1	25	.1000	.1000	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	2	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	3	25	10.0000	10.0000	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	4.8157	4	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	5	25	6.5000	6.5000	0.0000	25.7143
3.2301	2.8127	0	0	0.0000	0.0000	0.0000	0.0000
6.6176	1.9051	6	0	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	7	75	2.0000	2.0000	0.0000	75.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
3.4301	2.8696	8	0	0.0000	0.0000	0.0000	0.0000
2.9664	1.4285	9	49	-1.4053	-1.4053	204.7143	256.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	10	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	11	25	6.7979	6.7979	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	12	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	13	25	4.3418	4.3418	0.0000	25.7143
4.1329	1.0038	0	0	0.0000	0.0000	0.0000	0.0000
6.8979	-.0377	14	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	15	25	3.2813	3.2813	0.0000	25.7143
6.6979	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
6.6000	0.0000	16	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	17	25	6.1839	6.1839	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	18	0	0.0000	0.0000	0.0000	0.0000
6.4176	1.8235	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.9640	20	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	1.4820	22	0	0.0000	0.0000	0.0000	0.0000
4.1329	.9612	0	0	0.0000	0.0000	0.0000	0.0000
7.7478	1.1383	24	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
3.6997	2.7576	26	0	0.0000	0.0000	0.0000	0.0000
3.4997	2.6718	0	0	0.0000	0.0000	0.0000	0.0000
6.7979	3.0434	28	0	0.0000	0.0000	0.0000	0.0000
6.0164	3.6558	0	0	0.0000	0.0000	0.0000	0.0000
6.4370	.7572	30	0	0.0000	0.0000	0.0000	0.0000
2.5000	.5706	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	32	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	1.1267	34	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	36	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	3.4992	38	0	0.0000	0.0000	0.0000	0.0000
3.4997	2.7217	0	0	0.0000	0.0000	0.0000	0.0000
6.7275	1.4740	40	0	0.0000	0.0000	0.0000	0.0000
8.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
7.8126	.8452	0	0	0.0000	0.0000	0.0000	0.0000
7.2856	1.5321	0	0	0.0000	0.0000	0.0000	0.0000
6.5176	1.9319	0	0	0.0000	0.0000	0.0000	0.0000
5.7125	2.1476	0	0	0.0000	0.0000	0.0000	0.0000
4.9074	2.3633	42	0	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	43	75	-.8399	-.8399	0.0000	75.0000
7.1111	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
6.9445	.7513	0	0	0.0000	0.0000	0.0000	0.0000
6.4761	1.3619	0	0	0.0000	0.0000	0.0000	0.0000
5.7935	1.7172	0	0	0.0000	0.0000	0.0000	0.0000
5.0778	1.9090	0	0	0.0000	0.0000	0.0000	0.0000
4.3622	2.1007	44	0	0.0000	0.0000	0.0000	0.0000

```
  6.0000     0.0000    45    75    -.7466    -.7466    0.0000   75.0000
  8.0000     0.0000     0     0    0.0000    0.0000    0.0000    0.0000
  8.0000     0.0000     0     0    0.0000    0.0000    0.0000    0.0000
  7.8126      .8452     0     0    0.0000    0.0000    0.0000    0.0000
  7.2856     1.5321     0     0    0.0000    0.0000    0.0000    0.0000
  6.5176     1.9319     0     0    0.0000    0.0000    0.0000    0.0000
  5.7125     2.1476     0     0    0.0000    0.0000    0.0000    0.0000
  4.9074     2.3633    46     0    0.0000    0.0000    0.0000    0.0000
  0.0000     0.0000    47     0    5.1601    5.1601    0.0000    0.0000
  7.1111     0.0000     0     0    0.0000    0.0000    0.0000    0.0000
  7.1111     0.0000     0     0    0.0000    0.0000    0.0000    0.0000
  6.9445      .7513     0     0    0.0000    0.0000    0.0000    0.0000
  6.4761     1.3619     0     0    0.0000    0.0000    0.0000    0.0000
  5.7935     1.7172     0     0    0.0000    0.0000    0.0000    0.0000
  5.0778     1.9090     0     0    0.0000    0.0000    0.0000    0.0000
  4.3622     2.1007    48     0    0.0000    0.0000    0.0000    0.0000
  6.0000     0.0000    49    75    -.8399    -.8399    0.0000   75.0000
  0.0000     0.0000    51     0    4.5968    4.5868    0.0000    0.0000
  6.0000     0.0000    53    75    -.7466    -.7466    0.0000   75.0000
  1    1     1   11     5
  2   12     1   12     5
  3   13     1   14     5
  1    1     1   11     5     2    44     4     1     1     0     0     0     0
  2   11     1   12     5     2    42     4    44     2     0     0     0     0
  3   12     1   14     5     2     3     4    42     3     0     0     0     0
 -1    0     0    0     0     0     0     0     0     0     0     0     0     0
  0.0000
  1    1     1   11     5     2    44     4     1     1     0     0     0     0
  2   11     1   12     5     2    42     4    44     2     0     0     0     0
  3   12     1   14     5     2     3     4    42     3     0     0     0     0
 -1    0     0    0     0     0     0     0     0     0     0     0     0     0
  2.0000
  1    1     1   11     5     2    44     4     1     1     0     0     0     0
  2   11     1   12     5     2    42     4    44     2     0     0     0     0
  3   12     1   14     5     2     3     4    42     3     0     0     0     0
 -1    0     0    0     0     0     0     0     0     0     0     0     0     0
  4.0000
  1    1     1   11     5     2    44     4     1     1     0     0     0     0
  2   11     1   12     5     2    42     4    44     2     0     0     0     0
  3   12     1   14     5     2     3     4    42     3     0     0     0     0
 -1    0     0    0     0     0     0     0     0     0     0     0     0     0
  6.0000
  1    1     1   11     5     2    44     4     1     1     0     0     0     0
  2   11     1   12     5     2    42     4    44     2     0     0     0     0
  3   12     1   14     5     2     3     4    42     3     0     0     0     0
 -1    0     0    0     0     0     0     0     0     0     0     0     0     0
  8.0000
```

Zone 3 Burning

GRAIN MESH

14 5	39 3		1.00	*			
0.0000	0.0000	1	25	.1000	.1000	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	2	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	3	25	10.0000	10.0000	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	4.8157	4	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	5	25	6.5000	6.5000	0.0000	25.7143
3.6183	4.2616	0	0	0.0000	0.0000	0.0000	0.0000
7.0059	3.5539	6	0	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	7	75	3.5000	3.5000	0.0000	75.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
3.8163	4.3487	8	0	0.0000	0.0000	0.0000	0.0000
2.9664	1.4285	9	49	-2.9053	-2.9053	204.7143	256.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	10	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	11	25	7.6890	7.6890	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	12	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	13	25	5.6356	5.6356	0.0000	25.7143
5.3943	1.3112	0	0	0.0000	0.0000	0.0000	0.0000
7.7890	-.0571	14	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	15	25	4.2517	4.2517	0.0000	25.7143
7.5890	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
6.6000	0.0000	16	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	17	25	7.1756	7.1756	0.0000	25.7143
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	18	0	0.0000	0.0000	0.0000	0.0000
6.8059	3.2120	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	4.8955	20	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.4477	22	0	0.0000	0.0000	0.0000	0.0000
5.3943	1.2268	0	0	0.0000	0.0000	0.0000	0.0000
8.8653	2.1728	24	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
4.3757	4.1162	26	0	0.0000	0.0000	0.0000	0.0000
4.1757	4.0108	0	0	0.0000	0.0000	0.0000	0.0000
7.6890	4.4067	28	0	0.0000	0.0000	0.0000	0.0000
6.3000	-.2069	0	0	0.0000	0.0000	0.0000	0.0000
6.4370	5.9147	30	0	0.0000	0.0000	0.0000	0.0000
2.5000	.5706	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	32	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	1.1267	34	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	2.2824	36	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
10.0000	3.4992	38	0	0.0000	0.0000	0.0000	0.0000
4.1757	4.0939	0	0	0.0000	0.0000	0.0000	0.0000
7.5962	1.6392	40	0	0.0000	0.0000	0.0000	0.0000
9.5000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
9.1721	1.4792	0	0	0.0000	0.0000	0.0000	0.0000
8.2498	2.6812	0	0	0.0000	0.0000	0.0000	0.0000
6.9059	3.3807	0	0	0.0000	0.0000	0.0000	0.0000
6.9426	3.3709	0	0	0.0000	0.0000	0.0000	0.0000
6.9793	3.3611	42	0	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	43	75	.6601	.6601	0.0000	75.0000
8.4444	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
8.1530	1.3148	0	0	0.0000	0.0000	0.0000	0.0000
7.3331	2.3832	0	0	0.0000	0.0000	0.0000	0.0000
6.1385	3.0051	0	0	0.0000	0.0000	0.0000	0.0000
6.1712	2.9964	0	0	0.0000	0.0000	0.0000	0.0000
6.2038	2.9876	44	0	0.0000	0.0000	0.0000	0.0000

6.0000	0.0000	45	75	.5868	.5868	0.0000	75.0000
9.5000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
9.5000	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
9.1721	1.4792	0	0	0.0000	0.0000	0.0000	0.0000
8.2498	2.6812	0	0	0.0000	0.0000	0.0000	0.0000
6.9059	3.3807	0	0	0.0000	0.0000	0.0000	0.0000
6.9425	3.3709	0	0	0.0000	0.0000	0.0000	0.0000
6.9793	3.3611	46	0	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	47	0	6.6601	6.6601	0.0000	0.0000
8.4444	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
8.4444	0.0000	0	0	0.0000	0.0000	0.0000	0.0000
8.1530	1.3148	0	0	0.0000	0.0000	0.0000	0.0000
7.3331	2.3832	0	0	0.0000	0.0000	0.0000	0.0000
6.1385	3.0051	0	0	0.0000	0.0000	0.0000	0.0000
6.1712	2.9964	0	0	0.0000	0.0000	0.0000	0.0000
6.2038	2.9876	48	0	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	49	75	.6601	.6601	0.0000	75.0000
0.0000	0.0000	51	0	5.9201	5.9201	0.0000	0.0000
6.0000	0.0000	53	75	.5868	.5868	0.0000	75.0000

1	1	1	12	5									
2	13	1	13	5									
3	14	1	14	5									
1	1	1	12	5	2	45	4	1	1	0	0	0	0
2	12	1	13	5	2	43	4	45	2	0	0	0	0
3	13	1	14	5	2	3	4	43	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0000													
1	1	1	12	5	2	45	4	1	1	0	0	0	0
2	12	1	13	5	2	43	4	45	2	0	0	0	0
3	13	1	14	5	2	3	4	43	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
2.0000													
1	1	1	12	5	2	45	4	1	1	0	0	0	0
2	12	1	13	5	2	43	4	45	2	0	0	0	0
3	13	1	14	5	2	3	4	43	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
4.0000													
1	1	1	12	5	2	45	4	1	1	0	0	0	0
2	12	1	13	5	2	43	4	45	2	0	0	0	0
3	13	1	14	5	2	3	4	43	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
6.0000													
1	1	1	12	5	2	45	4	1	1	0	0	0	0
2	12	1	13	5	2	43	4	45	2	0	0	0	0
3	13	1	14	5	2	3	4	43	3	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0
8.0000													

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